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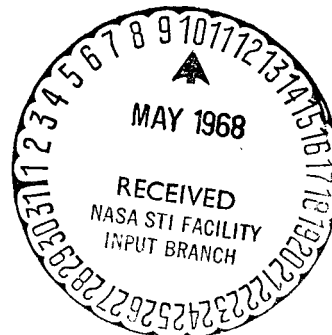
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PROTECTION OF NAVAL ENGINEER PERSONNEL AGAINST HEAT

Broussolle, P.Faltot and A.Bernardini

ABSTRACT. Four types of cool-air ventilation suits were tested in terms of applicability to surface vessels at the zero radiation level and submarines in regular duty in boiler and engine rooms: the C.E.P.S.M., Remco, CO.MA.SEC. type F and Frigivest. They were tested for both physiological performance and for practical use. Although inconsistent test parameters preclude final evaluation, specific criticisms are offered on all suits, and advantages and drawbacks are weighed. Precise data are given on the performances and inherent characteristics of the various models: autonomy of movement, comfort to wearer, sound muffling due to back-pack power source, etc.

1. Introduction

Statement of problem. In the Navy, engineering personnel may be exposed to extreme heat environments in two particular situations, namely: /37*

- the zero stage on surface structures; and
- submarine navigation in warm waters.

1.1. The Problem of the Zero Stage in Surface Structures

The zero stage is the position taken by a vessel crossing through an atomic cloud; all apertures are sealed, and ventilation with air from the exterior is either stopped or considerably reduced.

The result is a steady increase in the temperature, especially in the engine and boiler rooms. This temperature increase is more substantial and more rapid than that in structures in even the hottest of climates.

This is why in a tropical zone, the dry temperature increases to 55° in ten minutes, with a hygrometry of 50%, partial water vapor pressure of 58 mm Hg, and an air movement rate of practically zero. At this temperature, unprotected personnel exposed to it generally do not last longer than 15 minutes.

We may get an idea of the importance of engineering personnel necessary to maintain service on a squadron escort vessel during the zero stage, the vessel carrying 16 men who must be capable of functioning for an hour and one half:

- nine men for the two engines; and

* Numbers in the margin indicate pagination in the foreign text.

- seven for the two boiler rooms.

However, for technical reasons the boiler room is not completely protected from radioactive dust. Steps must be taken to guarantee that the seven men on watch after the zero stage and the three security men handling decontamination are equally protected. /38

Let us briefly examine the activity of engine-room artificers and stokers during the zero stage: this is a surveillance activity during which they may have to move about in the compartment. They must be able to hear and execute orders.

1.2. Problems of the "Power" Compartment of Submarines in Warm Waters

The various propulsion units of a submarine (generator groups, electrical engines and converters) and their auxiliaries produce a substantial amount of heat.

This heat can ultimately be dissipated only into the surrounding water through a thermal exchange at the submarine's hull level.

With exchange balance, the interior temperature stabilizes at a value above that of the ocean water.

The temperature variations between that of the sea water and that of the submarine interior have a mean value of 28°C for the engine room and a value of 8°C for the other compartments.

The watch personnel (four men) in the engine room perform eight hours of work per day in two periods of four hours each.

Their basic work is observing the instrument panels which show various data. Occasionally, they are also required to move several meters away from the panel. Finally, in response to an audio-visual alert signal, during a change in the propulsion or navigation, the personnel must perform a series of actions whose rapidity and precision have a direct bearing on the vessel's security. For an ocean water temperature of 28-30°C, the parameters for the thermal environment of the duty stations are the following: dry temperature 56-58°C, relative hygrometry 28-30%, partial water vapor pressure 35-40 mm Hg, and air speed of 0.30-0.40 m/s, whence an effective temperature of 36-37°C.

These difficult working conditions are aggravated even more by the fact that the rest area for the personnel shows a thermal environment clearly beyond the comfort zone (effective temperature: 28-30°C).

This situation of discomfort may last several sealing weeks, with the result that a state of chronic fatigue develops, particularly in personnel on watch in the engine room.

Because this fatigue decreases the military value of a vessel, research for a means of protecting the personnel has been shown to be indispensable.

2. How to Resolve the Problem?

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2.1. The Ideal Solution would be Complete Air-Conditioning of the Engine Room

2.1.1. Onboard surface vessels, the machine and boiler rooms represent a substantial volume (between one quarter and one fifth of the total cubic area of the vessel), with the result that it would be necessary to ventilate with a substantial amount of outside air. However, at the zero stage the outer air is contaminated and cannot be used. Only a small amount of air may be taken from outside after passing it through filters which would deactivate it.

The solution of complete ventilation of the compartment should therefore be rejected.

2.1.2. Onboard submarines, because of the substantial amount of heat-generating equipment collected into a small area, complete conditioning of the engine room is impossible. Simple calculations show that this would require an inadmissible amount of power.

2.2. We Therefore Arrive at the Solution of Air-Conditioning the Cabins in which the Personnel are Grouped.

On a squadron escort vessel, we would therefore have four large air-conditioned cabins, each having three to five men.

Such a cabin exists, for example, on the aircraft carrier Foch, the volume of air necessary to ventilate the cabins exceeding present-day air-filtration capabilities.

On the other hand, the installation of these cabins on vessels not originally having them would give rise to substantial problems.

Finally, the engine personnel would have to leave the room for various control duties, and the problem would not be entirely resolved. In the same way as in submarines, this solution, although feasible for large-tonnage atomic vessels, is excluded in conventional submarines with their small area.

2.3. Thereby gradually decreasing the area to be air-conditioned from the entire engine room, by cabin, we arrive at the position of having to produce a microclimate around each individual, within certain special clothing.

For this individual protection, we have available four articles of clothing of two different types:

- a) Three garments using fresh-air circulation in an open circuit;
 - 1. The C.E.P.S.M. prototype suit,
 - 2. The REMCO prototype suit with an air-circulation tube; and
 - 3. The type F CO.MA.SEC suit.

b) A garment making use of a closed air-circulation system with the air locked in the garment and passing through a cooling source, namely the FRIGIVEST garment.

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We would like to compare these garments both from the point of view of their physiological performances as well as from the viewpoint of their practical use.

2.3.1. The C.E.P.S.M. Garment

It consists of a combination suit of flexible rhovyl fabric and a removable hood with a rhodoid visor.

The fresh air is obtained by passing the hot air within the compartment through an iced water-exchanger through a ventilator. This fresh air reaches the top of the hood through a very light flexible tube 40 mm in diameter. The air flow is 1 m³/mn.

The total weight for the garment is 1.500 kg.

2.3.2. The CO.MA.SEC type F

The complete piece of equipment contains:

- On one hand, an outside combination suit of aluminized fabric and a hood which may be lengthened by a cloak which is also aluminized fabric and which protects the upper part of the body;

- And on the other hand, an inside combination suit of fireproof fabric which carries a network of flexible tubes which distribute the air to 64 points over the trunk, arms and legs.

The hood and inside combination suit are fed through the release of compressed air.

The air flow in the under garment and the hood is 450 l/mn for a garment input feed pressure of 2 kg/cm².

The timetable consumption is 27 m² of air measured after expansion.

The total weight for the equipment is 5.500 kg.

2.3.3. The REMCO Garment

The REMCO garment is a cloak-like garment 7-8th insulating fabric with attached hood.

Under the hood there is a second inflatable hood pierced with small holes which assure the distribution of fresh air to the head and neck level. This air then descends around the length of the body and arms to the extremities, where it goes out. The legs are not protected.

The cool air feed in the hood is achieved through a microgenerator (air expansion in an air-circulation tube based on the Ranque principle). 60% of the compressed air fed into the cooling generator is cooled from 50°C. A "by-pass" permits mixing part of the air furnished with the cool air going out in order to increase the expansion in the garment and adjust the temperature.

2.3.4. The FRIGIVEST Garment

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The garment itself is in two parts, a jacket with a hood having a rhodoid opening, and pants. It is made of aluminized fabric or tempex fabric.

The hood fits over a rigid helmet which facilitates movement of the head.

A plastic unit attached to the man's back by straps encloses a container filled with a eutectic mixture pre-frozen at -18°C. At the base of the frame, a fan blows the warm air from inside the garment, and makes it pass over the container where it is cooled, injects it into a large-section tube on the end of which there is a large plastic nozzle which distributes the cool air over the chest.

To the side of the frame are fixed cadmium-nickel batteries which drive the fan for four hours. The weight of the frame with container is 6.600 kg.

Although the ventilation is in a closed circuit, the rate of CO₂ has not exceeded 0.8% standing and 1% sitting at rest. In fact, there are exchanges with the exterior through the garment's extremities, through movements of the blower.

3. Tests in Climate Chambers

The four garments have been tested and compared in the sealed climate chamber at the C.E.P.S.M. laboratory where the various parameters: dry temperature, radiant temperature, and partial water vapor pressure, may be set and regulated.

During the tests, the environment reproduced the thermal overload which exists in the engine rooms of surface vessels at the zero stage and in submarines passing through warm waters.

3.1. Physical Parameters of the Environment

Dry temperature: 55° ± 1°C.

Radiant temperature: 55° ± 1°C.

Relative hygrometry: 28° ± 2%.

Ventilation: below 20 cm/s.

3.2. Physiological Study Method

The protection offered by the garments has been established through study of the thermal balances and the value of the Craig index.

1. We studied these balances in subjects standing in even temperatures, then dressed in each of the four garments in a high-temperature chamber, through the method of fractional calorimetry, which consists of determining the heat storage according to the mean temperature variation in the body. The balance is calculated by the following equation:

$$B = t_n \times C_p \times P,$$

where:

B is the caloric balance in Kcal/h, restored to m^2 of body surface;
 t_n is the change in mean body temperature in degrees C;
 C_p is the mean specific heat of the body in Kcal/kg/8°C (0.83);
P is the body weight in kilograms.

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The mean body temperature is calculated by the Burton formula (1):

$$t_m = 0.33 t_c + 0.67 t_r,$$

where:

t_c is the mean cutaneous temperature;
 t_r is the deep rectal temperature.

The mean cutaneous temperature is determined through measurement of the temperature on seven cool points by the following coefficients (2):

Back: 0.19,
Thigh: 0.32,
Chest: 0.19,
Cheek: 0.14,
Forearm: 0.11,
Palm: 0.05.

2. The Craig index (3), an index of physiological constraint, is equal to:

$$I_{\text{Craig}} = \frac{P_c}{100} + t_r + p,$$

where:

P_c is the heartbeat at the end of the test,
 t_r is the change in the rectal temperature in degrees C,
p is the subject's weight loss in kilograms.

Experimental Procedure

We used seven subjects, mostly doctors and engineers, and the tests were always made at the same hour of the day, well between meals, and after two hours of rest at median temperatures.

We ran two series of tests, one in the high-temperature chamber and the other at normal temperatures.

During the two series, the following measurements were taken:

- subject's weight nude before and after (quantity of water lost),
- weight of garments before and after (quantity of non-evaporated sweat),
- heartbeat: continuous measurement through Sintra cardiometer,
- central temperature: continuous measurement of deep rectal temperature through thermistor probe,
- cutaneous temperatures: continuous measurement through seven cutaneous thermistors, /43
- measurement of physical parameters of the air by dry-bulb and wet-bulb (psychrometer) thermometers and black-bulb thermometer,
- measurement of the low-pressure air temperature at the garment inputs through classical and thermistor thermometry. The length of each test was one hour and a half, the balances being calculated during the last 60 minutes (Figures 19 and 20).

Feed to the Garments

C.E.P.S.M. Garment:

The exchanger sets the air at 21°C , 66% hygrometry, water vapor partial pressure 12 mm Hg and a flow of $60\text{ m}^3/\text{h}$. The pressure loss in the garment does not exceed several cm/H₂O.

The REMCO Garment:

The temperature of the compressed air at the microgenerator is $55^{\circ} \pm 1^{\circ}\text{C}$ (ambient temperature).

Operating pressure: 5 kg/cm^2 .

Total flow at this pressure: $24\text{ m}^3/\text{h}$, approximately 60% in the garment.

CO.MA.SEC Garment:

Air temperature at garment input: $15^{\circ} \pm 3^{\circ}\text{C}$. The air comes from the expansion of air compressed at 100 kilograms with very weak hygrometry.

Operational pressure: 2 kg/cm^2 .

Flow at this pressure: $27\text{ m}^3/\text{h}$.

FRIGIVEST Garment:

Containers for eutectic mixture frozen at -18°C .

Container changed every half hour.

Surface life of cadmium-nickel battery: four hours.

3.3. Interpretation of Results

Examination of the results of the caloric balances and the values of the Craig index indicates that the garments do not offer perfect protection.

In fact, in these tests there still exists a certain degree of putting into play of the physiological mechanisms in the battle against heat.

Statistical comparisons of the fractional calorimetry balances B' and B'-B are not significant at a security threshold of $P = 0.05$.

The physiological protection of the various types of garments therefore seems to be equivalent. However, these comparable caloric balances are obtained at the price of a variable sudoral elimination.

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Statistical comparison of the Crain indexes and the quantities of sweat eliminated per square meter and per hour yield the following results:

Comparison of garments:

- types C.E.P.S.M. and FRIGIVEST is significantly in favor of the C.E.P.S.M.,
- types C.E.P.S.M. and REMCO is significantly in favor of the C.E.P.S.M.,
- types C.E.P.S.M. and CO.MA.SEC is not significant,
- types FRIGIVEST and REMCO is not significant,
- types FRIGIVEST and CO.MA.SEC is significantly in favor of the CO.MA.SEC,
- types REMCO and CO.MA.SEC is significantly in favor of the CO.MA.SEC.

From this it results that under selected experimental conditions, the types C.E.P.S.M. and CO.MA.SEC garments offer the most substantial protection. Nevertheless, let us bear in mind that the C.E.P.S.M. garment was fed air at a temperature of 21°C and the CO.MA.SEC garment was fed at a mean temperature of 14°C with very dry air.

It would be useful to recompare the two types of garments and improve the technical conditions of experimentation, which would permit us to lower the feed temperature to the C.E.P.S.M. garment.

On the other hand, a very recent technical modification on board surface vessels has permitted a drop in the air temperature at the input of the REMCO microgenerator. This fact would again make this type of garment highly competitive.

4. Applications of the Study Onboard Vessels

4.1. Onboard Submarines

Economy of power is imperative, for it is this which determines the radius of action during deep dives, and therefore its application.

In fact, recharging batteries requires either navigation at snorkel depth or on the surface, phases during which the submarine is detectable and therefore vulnerable.

4.1.1. Balance of Energies Necessary for the Functioning of Each Garment

4.1.1.1. C.E.P.S.M. Prototype Garment

The ambient air (55°C, 28% hygrometry) taken in through a fan passes over a heat exchanger fed through a source of refrigerated glycolated water available on board, which yields approximately 1600 large calories/hour which requires the use of a refrigerating installation with the power of 800 watts per garment. /45

The power consumed by the fan and the glycolated water pump are respectively 200 and 100 watts.

Which amounts to a total power of 1100 watts per garment.

4.1.1.2. Garments Fed Through Low-Pressure Compressed Air

1. The REMCO Prototype Garment:

The only power to be considered is that which corresponds to compression of the ambient air from 1 bar to 6 bars absolute. The flow of air consumed being reduced to 24 m³/h under normal conditions and allowing for an isothermal compression (at 55°C), the theoretical power required is 1400 watts per garment (without taking into consideration the yield).

2. Type F CO.MA.SEC. Garment:

For a flow of 27 m²/h, reduced to atmospheric pressure, the feed pressure for the garment is 3 bars absolute.

The isothermal compression requires a power of 1000 watts per garment. This compressed air passes over an exchanger at 55°C at which it loses 630 kcal/h to be reduced to a temperature of 20°C. This cooling requires a refrigeration unit which consumes approximately 300 watts.

Which amounts to a need for 1300 watts power for the CO.MA.SEC type garment.

4.1.1.3. FRIGIVEST Garment:

Each container must be frozen at -18°C, which requires a power of 1500 watts per garment.

Briefly, the power consumed by the various garments is:

C.E.P.S.M. Prototype: 1100 watts,
REMC0 Prototype: 1400 watts,
CO.MA.SEC: 1300 watts,
FRIGIVEST: 1500 watts.

These powers are of the same order, although the C.E.P.S.M. prototype has a slight advantage.

4.1.2. Other Factors which Also Affect our Choice

4.1.2.1. FRIGIVEST Garment.

Its use is excluded on submarines for the following reasons:

- during dives, the average amount of CO₂ is 1%, with the result that confinement inside the garment becomes inadmissible,
- the freezing time for a container being eight hours, a total of 96 containers would be required for the four garments. It is impossible to stockpile such a cubic-foot amount of containers at the expense of the supply of deep-frozen provisions preserved in the cold-storage chambers,
- finally, the weight of the garment and the encumbrment of the back container make its use impossible for eight hours' duty per day within the narrow constraints of the engine room.

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4.1.2.2. The REMCO and CO.MA.SEC Garments using Low-Pressure Compressed Air are Eliminated for the Following Reasons:

During dives, the submarine is a closed area which must remain at atmospheric pressure. This excludes reducing the pressure of air taken from vital compressed-air supplies at 250 bars required by other essentials for the submarine's security.

They only possible solution is to compress the ambient air. Now the continuous operation of an on-board compressor is excluded because of the noise produced. The noise would make the submarine detectable and, through its masking affect, upset the submarine's on-board sonar equipment.

4.1.2.3. The Garment being Considered at Present is the C.E.P.S.M. Prototype

This garment consumes the least energy and is therefore the most suitable for use on board submarines.

It is easily adaptable on a cold-air exchanger fed by refrigerated glycolated water which already exists in the engine room.

During physiological tests, the heat exchanger was fed with water having a temperature of 15°C. This temperature represented a maximum condition for on-board use, and the garment would certainly perform better than that. The

fact that the garment is very light and easy to put into use is a significant argument in its favor, because of the fact that it must be worn eight hours per day over a period of weeks.

However, the air intake into the garment at the helmet level produces a masking effect for the reception of sound signals and conversation.

The men would therefore have to be equipped with a light anti-noise helmet with built-in headphones, transmission being made through wire hookups or through magnetic loops, with improvements possible:

The noise level in the helmet could be lowered by feeding the garment at the lumbar level and diverting only one flow of air toward the helmet. This arrangement would also have the advantage of distributing the fresh air more evenly throughout the garment. The best solution would be to distribute the air throughout the body area through the use of a CO.MA.SEC-type ventilated sub-garment with a very low energy loss.

4.2. On Board Surface Vessels

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The problem is quite different: the duty station for the engine-room personnel at the zero safety level is a situation which happily is very rare and does not exceed an hour and a half.

In addition, the power economy which is imperative on a submarine poses less serious problems on surface vessels, where the energy which will be consumed through ventilating the garment arrangement will be negligible with respect to the total energy used on board.

It is for this reason that a priori the four solutions for the garments which we have outlined can be achieved on a surface vessel.

However, let us examine the advantages and drawbacks posed by the use of these various garments under actual operational conditions.

C.E.P.S.M. Prototype Garment

Whereas this garment is very well adapted to submarine conditions, where it takes advantage of the circulation of cold glycolated water from on board to recool the ventilation air used, it would necessitate an additional installation on a surface vessel, for which fact we must reject it.

It seems more logical to think in terms of using either a garment ventilated through compressed air from on board, such as the REMCO and CO.MA.SAC garments, or by an independent system such as the FRIGIVEST. It is therefore toward these latter solutions that we turned our attention.

Experimentation in climate chambers has shown us that none of the three following garments is entirely satisfactory. Under the conditions which we used, they almost always brought into play the physiological mechanism of temperature control: sudation, and increase in pulse. The temperature within these garments is therefore above 32-35. The following improvements are thus

required: a decrease in the ventilation air temperature, an increase in the flow, and better distribution of the air within the garment.

At the present level of our experimentation, it is especially in terms of the practical aspects of on-board use that we can make proposals for future experimentation.

The FRIGIVEST Garment

The basic advantage of this garment is its independence, which makes it ideal for short-term use. In fact, the cold source is within the garment and there is no cable or tube to connect it to an external installation.

It is easy to put on. It is for this reason that we experimented with it on board the Galissonniere, going through all the motions of adjusting valves and the subject's movements were always made easily in both the boiler room and engine room.

However, under the operational conditions at the zero safety level, the cold-mixture container must be changed every half hour. This therefore requires a substantial stockpile of containers: 48 for one half hour at the zero level and 96 allowing for the possibility of a second zero level less than eight hours after the first. These containers must be stored in an area at -18°C and outside the engine room, and every half hour an additional man must enter the compartment to make the change.

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On the other hand, in this garment as in the other three, the subject cannot communicate with the outside and must add a microphone placed inside the hood and tied by a telephone cable. The advantage of independence in this garment is therefore substantially reduced under these conditions.

Other Drawbacks

The 6.600 kg weight of the container-carrier is bothersome on the shoulders for a period of an hour and a half.

Ventilation is poorly distributed, with only one chest outlet.

This garment cannot be used in the boiler room. We have in fact said that this area may be contaminated through radioactive waste, and in the FRIGIVEST the outside air enters the lower part of the sleeve and the pants. It is therefore absolutely necessary that we have a garment ventilated with air under slight overpressure.

In summary, this is an independent garment, but should be reserved for short-term use, which is not the case at the zero level.

The REMCO Garment

The basic advantage lies in the fact that the original cold-production system is light, strong and efficient, since it lowers the temperature from 50°C.

It is easy to put on.

The material is strong.

Movements are easy with it on, and the small cross-section of the feed tube is not bothersome.

Drawbacks

The prototype garment is cumbersome and does not protect the legs.

The noise created by the cold generator is bothersome during a period of an hour and a half. The air distribution from the hood is not even, particularly around the arms.

However, the garment's shape can be improved and a noise attenuator is planned for later garments (anticipated level: 50 decibels).

In addition, the lack of freedom created by the existence of the feed tube may be eliminated if air intakes are installed in the compartment where the wearer could hookup rapidly as he moves around.

Under our experimental conditions, we introduced air into the cold micro-generator at 55°, the temperature in the compartment in which the air would have to be stored. The technical usage conditions were modified when the physiological experimentation was over: it will be possible to take air from the general on-board compressed-air circuit whose temperature does not exceed 30-35°C. The garment will thereby be improved even more, and a series of tests should be resumed now. /49

The CO.MA.SEC Garment

Its basic advantage is the excellent ventilation air distribution through the system of multiple tubes, which offers substantial comfort.

The garment is supple and movements are thus very easy.

In putting the garment on, there is the inconvenience of having two successive garments to get into.

The feed tube, larger than the one for the REMCO garment, is bothersome during movement.

A major drawback is the cool-air feed, because it has no independent cooling system. However, now that we can use the on-board compressed air system and no longer a single air source in the machinery compartment, it is possible that through successive expansion we will achieve a sufficient drop in the air to feed the CO.MA.SEC garment directly. This is an experiment which we have yet to make.

Conclusion

For the conditions at the zero level in a surface vessel, we are planning to use two types of garment: the REMCO and the CO.MA.SEC.

Neither is entirely satisfactory on the physiological plane, but the drawbacks are acceptable because of the short time and the exceptional conditions when the garment is used.

Each garment has its own advantages and disadvantages from the technical viewpoint and at the present state of our experimentation it is impossible to make a definite choice. In fact, the experimental technical conditions have not permitted us to feed the various garments identically, so that it is not a question of making a value judgment. We have indicated the work which remains for us to accomplish with each garment in order to improve it. It is even logical to combine the advantages of one process with those of another, such as: a cold source which contains an air-circulation tube feeding a ventilated undergarment which gives excellent air distribution.

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